

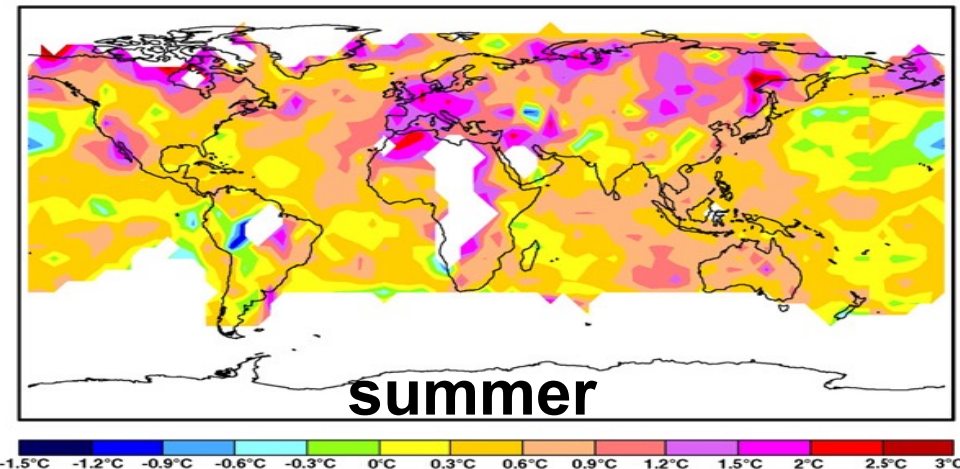
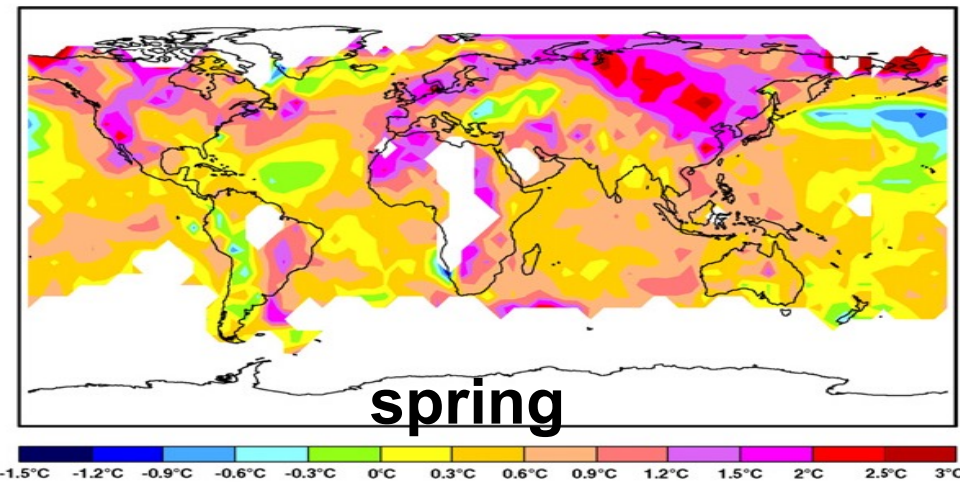
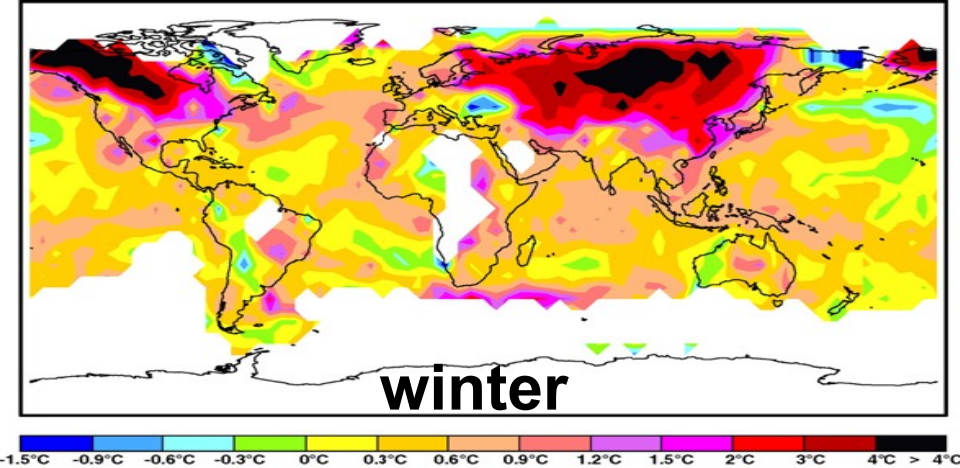
# Biomass burning smoke plume injection height: CALIOP-based estimates and comparisons to CMAQ

Amber J. Soja, Hyun-Deok Choi, George Pouliot, T. Duncan Fairlie,  
David M. Winker, Mark Vaughan, Thomas E. Pierce,  
Charles Trepte, and James Szykman

Photo courtesy of  
Brian Stocks







Mean seasonal temperature change.

Temperatures are increasing, particularly in the Northern Hemisphere winter and spring, which has lead to longer growing seasons, increased potential evapotranspiration and extreme fire weather.

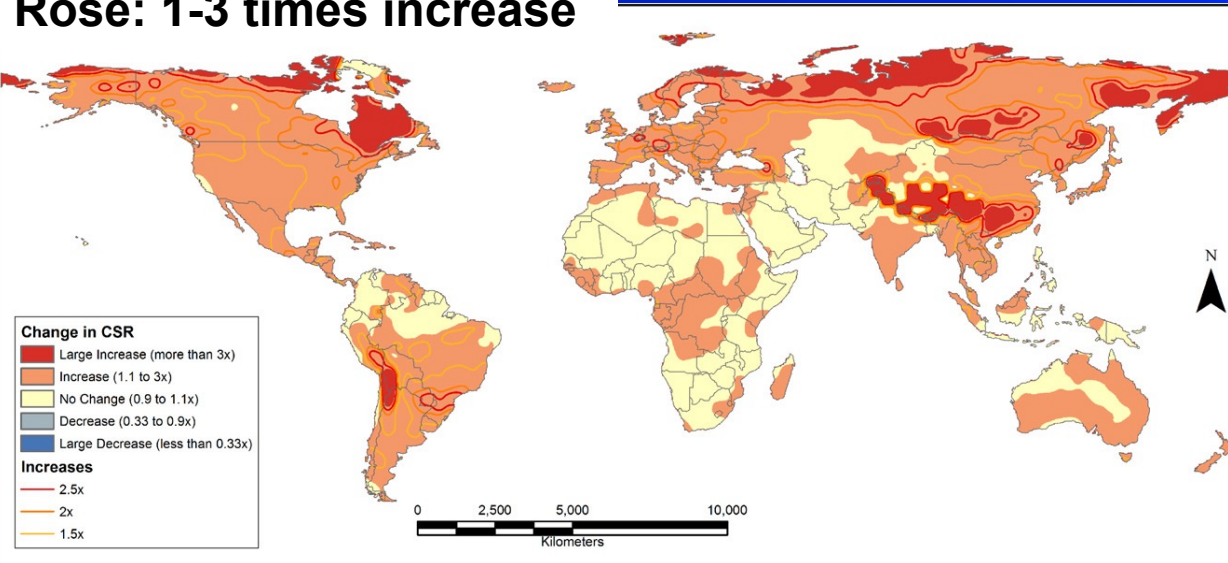
**It is time to get fire feedbacks integrated.**

[Groisman et al., 2007; Jones and Moberg, 2003, updated]



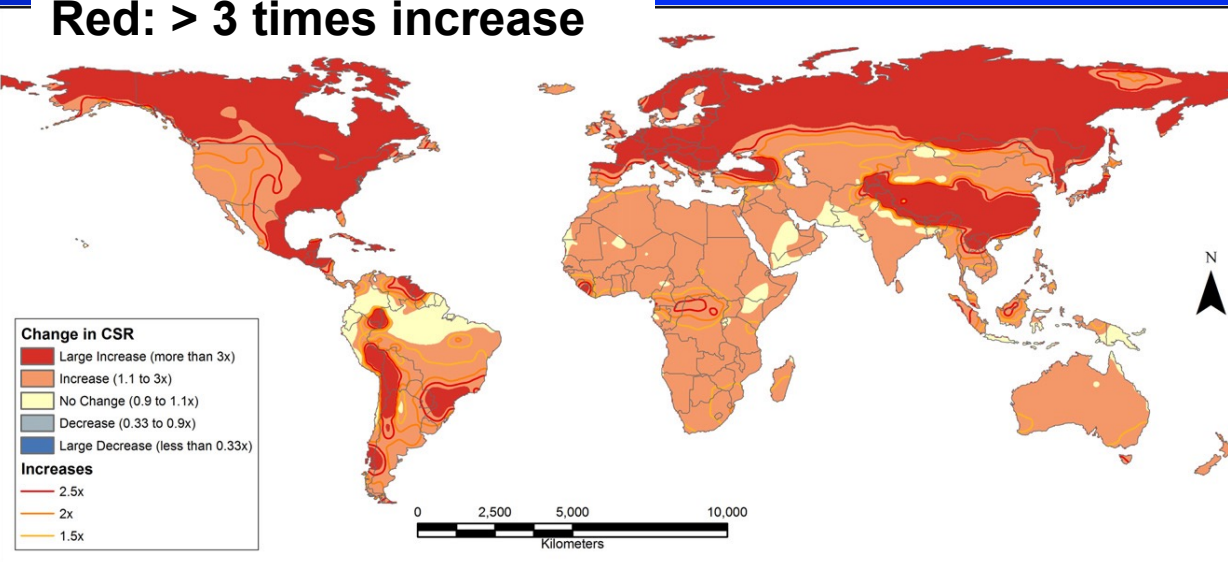
# Predicted Cumulative Fire Severity Rating

**Rose: 1-3 times increase**



Anomalies for  
2041–2050,  
relative to 1971–2000  
base period.

**Red: > 3 times increase**

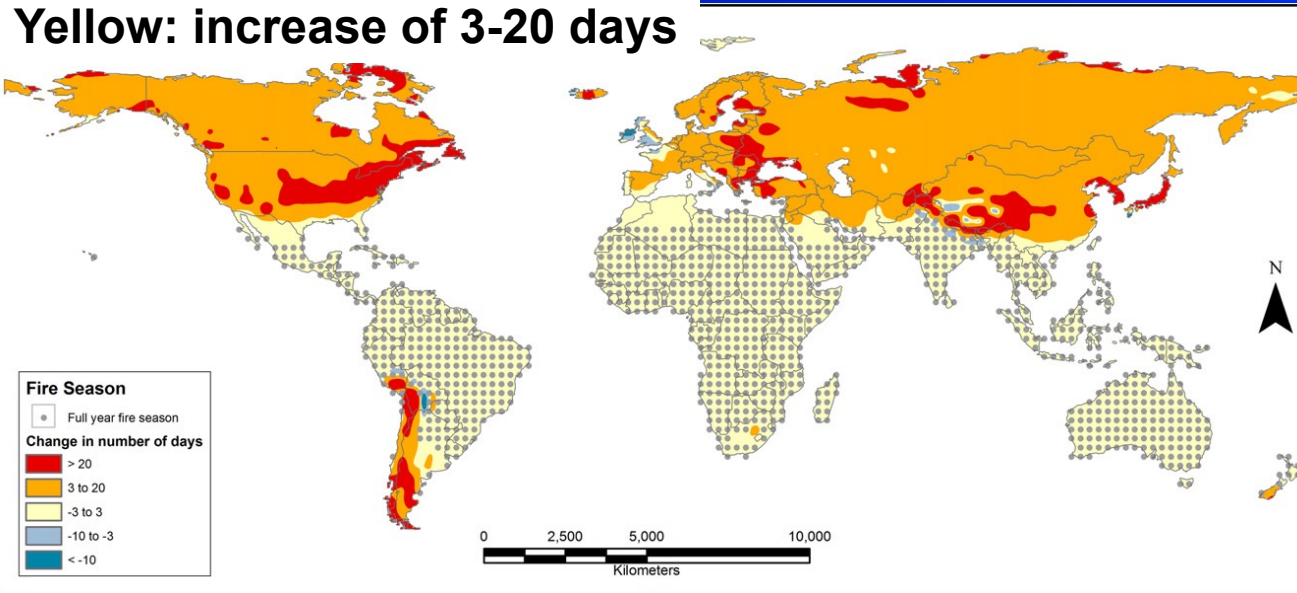


Anomalies for  
2091–2100,  
relative to 1971–2000  
base period.



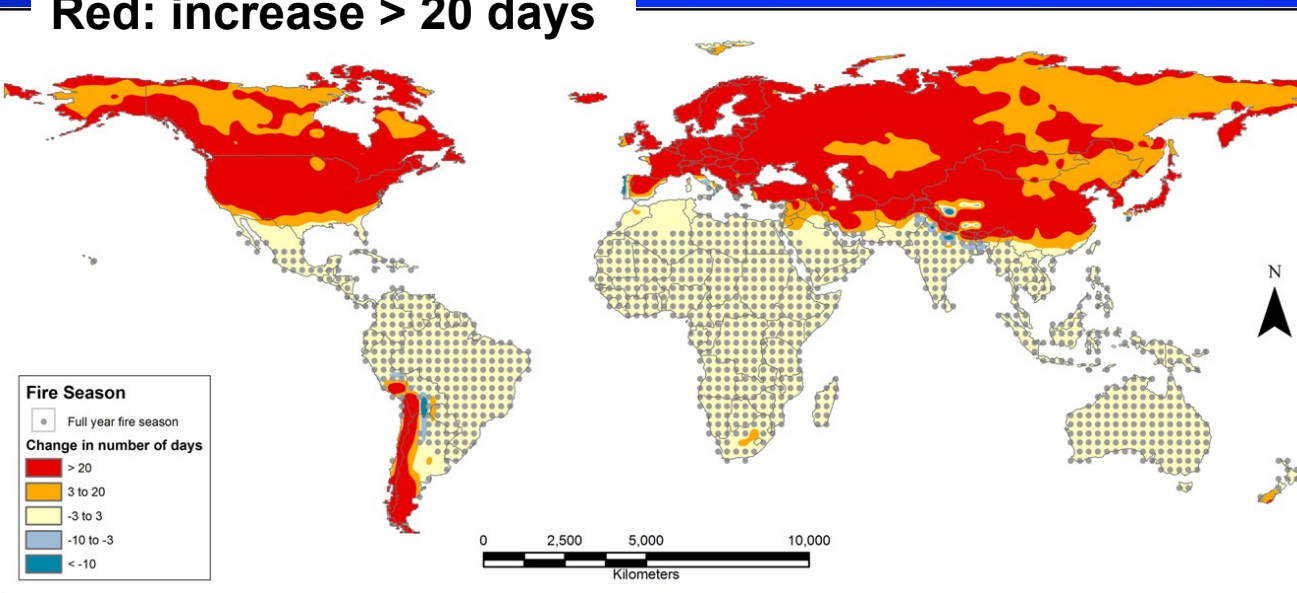
# Predicted Fire Season Length

**Yellow: increase of 3-20 days**



**Anomaly for  
2041–2050,  
relative to 1971–2000  
base period.**

**Red: increase > 20 days**



**Anomaly for  
2091–2100 relative  
to 1971–2000  
base period.**

**Flannigan et al., 2013 Modeled based on Hadley CM3 B1 scenario**



**If we don't get injection height correct, the transport of pollutants will be incorrectly modeled and tracked.**

### **Air Quality**

- \* a mis-informed public (air quality reports), which could adversely affect human health;**
- \* an inability to quickly and accurately assess the Exceptional Events Rule (72 FR 13560, March 22, 2007).**

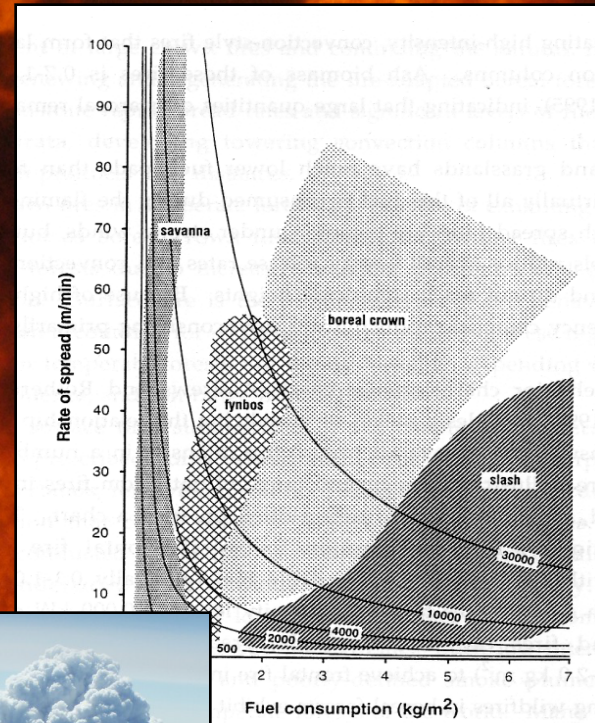
### **Climate Feedbacks**

- \* Smoke alters the Earth's radiation balance and feedback to climate change [e.g., patterns of precipitation (cloud condensation nuclei), change in Earth's reflectance - albedo (vegetation change, clouds, black carbon on snow and ice)].**



# Fire Intensity-Energy Release-Plume Height

- ❖ Combine rate of spread/fuel consumption/heat of combustion to determine fire intensity ( $I = HWR$ ) = resistance to control
- ❖ Savanna Fires:
  - 10-12 t/ha
  - 500-10,000 kW/m
  - Lower convection columns
- ❖ Boreal/Temperate Forest Fires:
  - 25-50 t/ha
  - 100-100,000 kW/m
  - > fuel consumption & intensity
  - Towering convection columns reaching UTLS



A typical high-intensity boreal crown fire convection column viewed from an altitude of ~10 km (*photo courtesy Mr. Todo, JAL*)

**Driving force:**  
**Fire Weather and Fuel**



# Fire Regimes Vary Widely

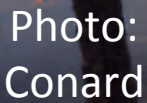


Photo:  
Conard







What burns and how dry are the fuels does matter.

Photos: Stocks and Soja





**June 28 2008**  
**Columns near Lake Athabasca:**  
**5-6 km**

**ARCTAS: Photos courtesy P3 group**

**Air and smoke travel faster at higher altitudes**

**Climate → Weather → Available Fuel → Injection height**

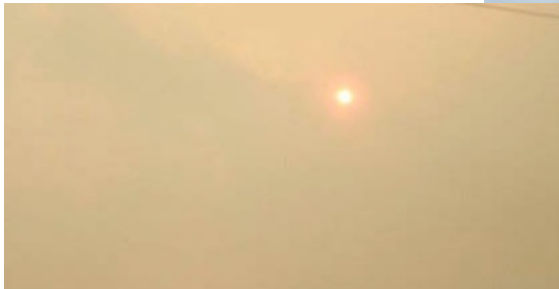


**Fires between  
Athabasca and  
Reindeer Lakes**

**June 30 2008**



**5-7 km**



**ARCTAS:  
Photos courtesy  
P3 group**

**Air and smoke travel faster at higher altitudes**

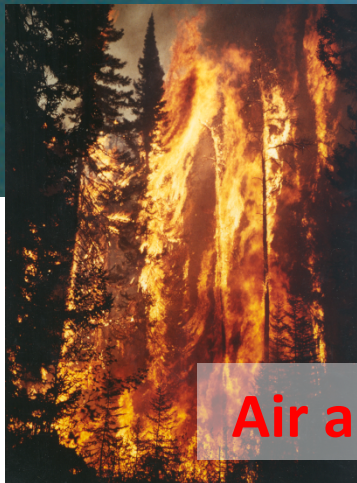
**Climate → Weather → Available Fuel → Injection height**



# Typical pyroCb convection columns (10-12 km)



Typical pyroCb fire behavior: continuous high-intensity crown fires



**Air and smoke travel faster at higher altitudes**

Climate → Weather → Available Fuel → Injection height





**1 year after burn**

# History

*Historically, plume height based on the pioneering work of G.A. Briggs [1969; 1971] and verified with limited field campaign data [Clements et al., 2007].*

*We have an increasing number of ground-based lidar and aircraft verification measures, as well as models (Frietas).*

*There are currently 2 satellites that can provide the statistics necessary to understand and verify plume height.*

**I. MISR - Multi-angle Imaging SpectroRadiometer**

**II. CALIPSO - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation**



## **CALIPSO**

- \* Increased capability of detecting optically thin smoke layers at a finer vertical resolution;*
- \* Able to identify plume heights from extensive smoke fields;*
- \* Paired with back trajectories, smoke plume identification are temporally random, representing the entire temporal range of fire plumes.*

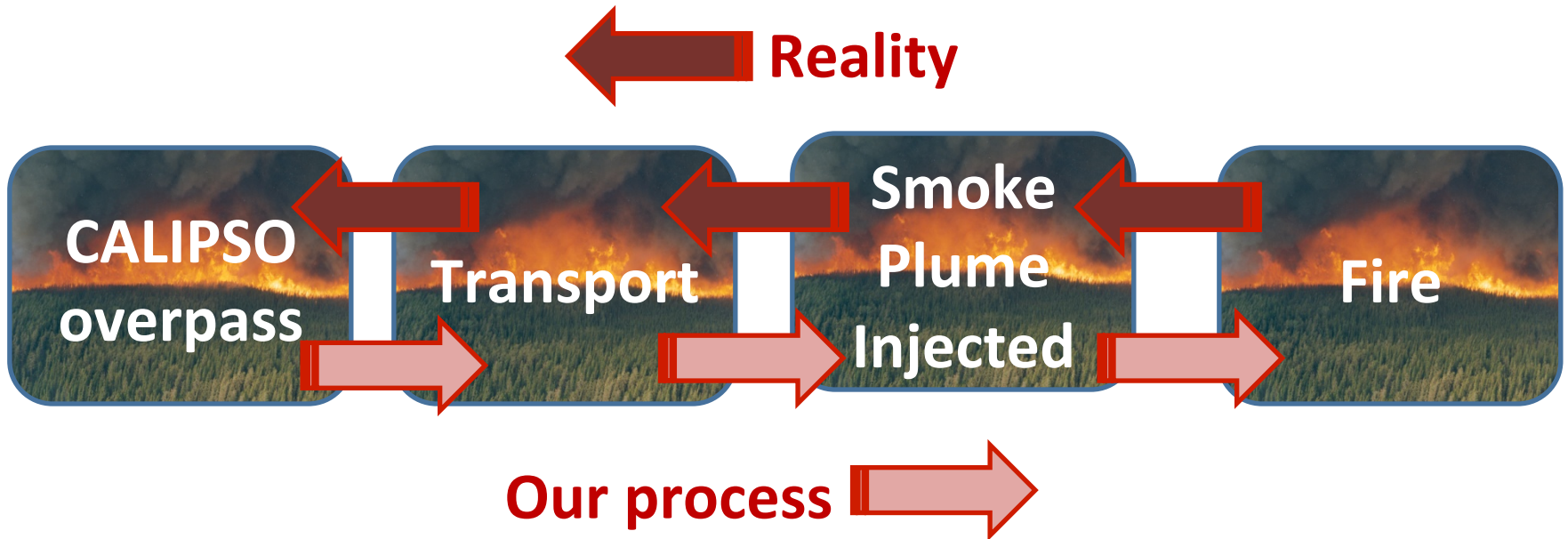
## **MISR**

- \* needs abrupt well-defined columns - relies on multi-view angles to estimate the stereo height of distinct features;*
- \* substantially larger swath width than CALIPSO which results in a greater opportunity to capture smoke plumes [Kahn et al., 2007]; &*
- \* morning overpasses do not capture the natural temporal fire pattern.*

Sensor (spacecraft)	Product	Spatial Resolution	Satellite Overpass	Temporal Availability
MISR (Terra)	AOD, aerosol plume height	1.1 km horizontal x 500 m vertical	10:30 a.m.	~ Once every 7 days
CALIOP (CALIPSO)	extinction profile	100 m diameter x 30 m vertical	1:40 p.m.	Once every 16 days



# Methodology



- Coincidence in CALIPSO tracks & NOAA Hazard Mapping System (HMS) smoke plume data;
- LaRC trajectory model (backwards);
- Coincidence with MODIS fire detection.

**All in 3-dimensional space and time**



# Each CALIOP air parcel is associated with the following related parameters:

## Fire

Number of active Fire Detections  
(MODIS Terra and Aqua)

Fire Radiative Power

## Land

IGBP vegetation 1km MODIS

Elevation

Available fuel

## Langley Trajectory Model (LaTM)

Air parcel counts, mean range

## Meteorological

Relative Humidity (2m, 10m)

Temperature (2m, 10m)

Wind speed and direction

Precipitation

Fire weather

Time of day

Planetary Boundary Layer

Stable Layer

## Location

Latitude/longitude

fire location and plume

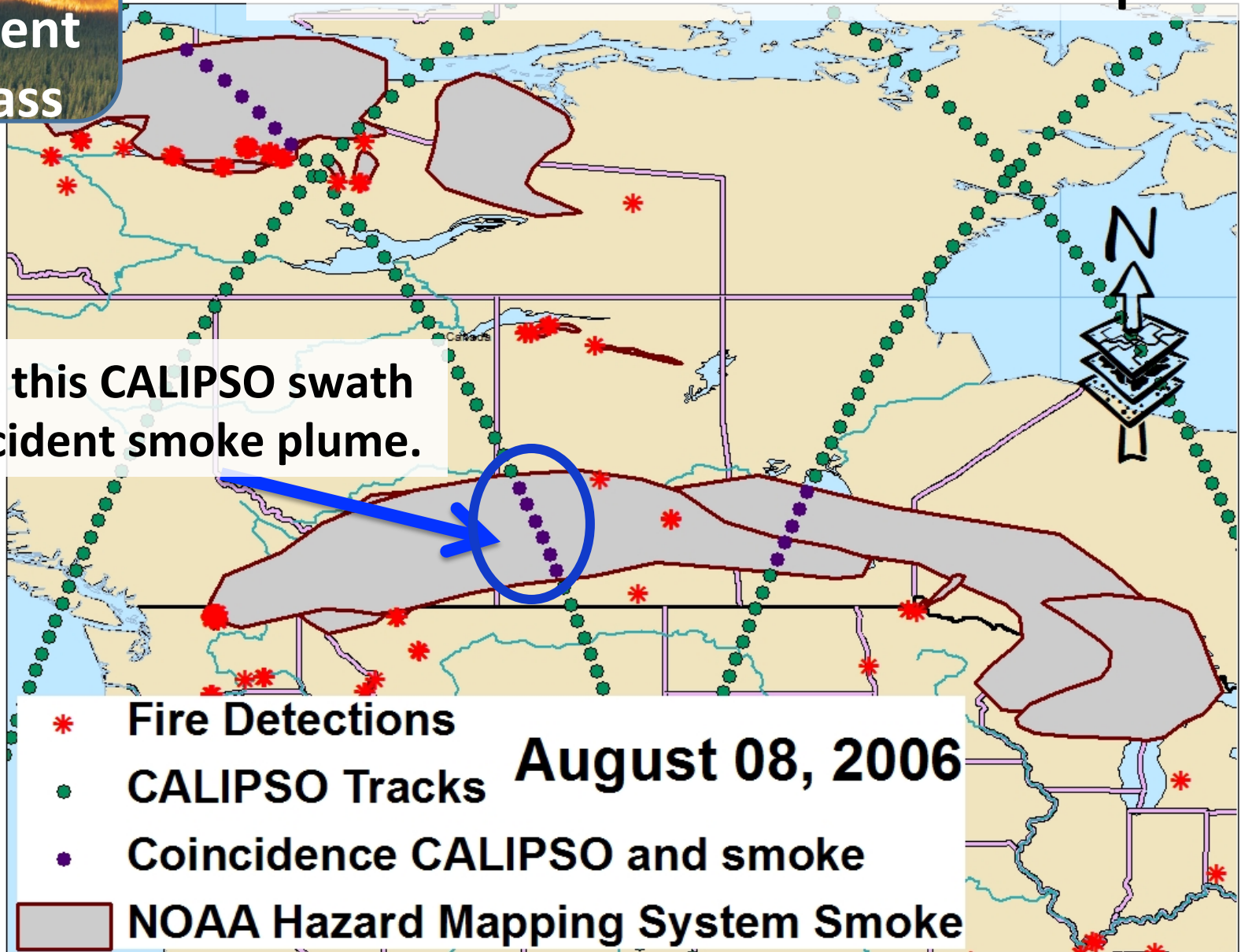
Fire name



**Plume and  
CALIPSO  
Coincident  
Overpass**

**Coincident NOAA HMS smoke plume,  
and CALIPSO overpass.**

**Focus on this CALIPSO swath  
and coincident smoke plume.**

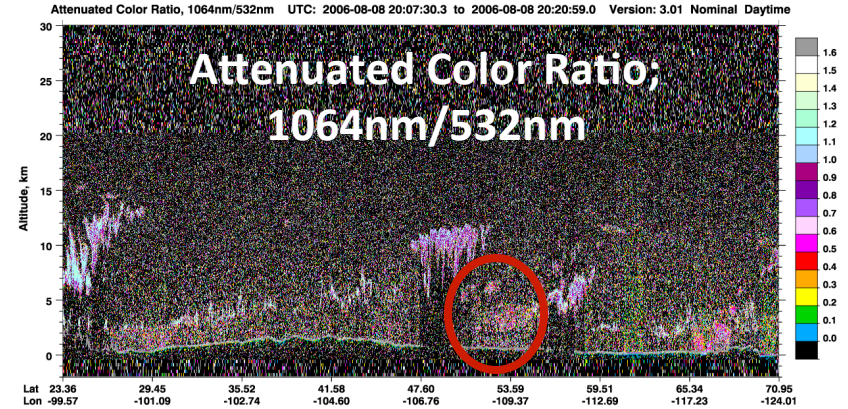
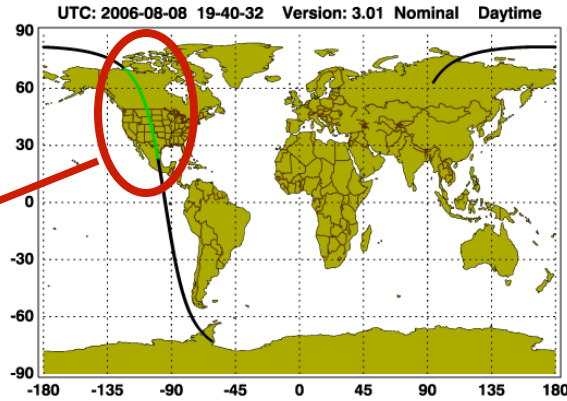




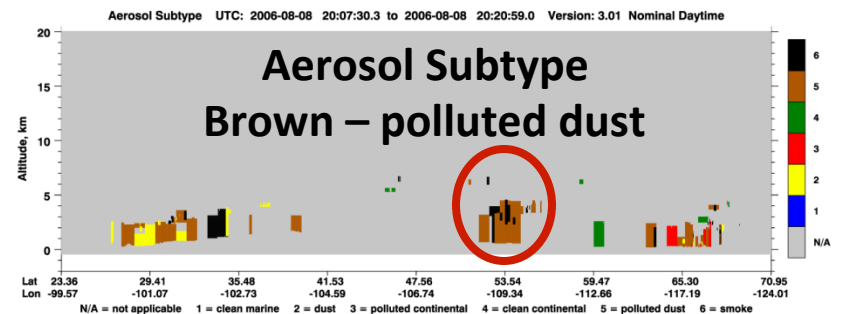
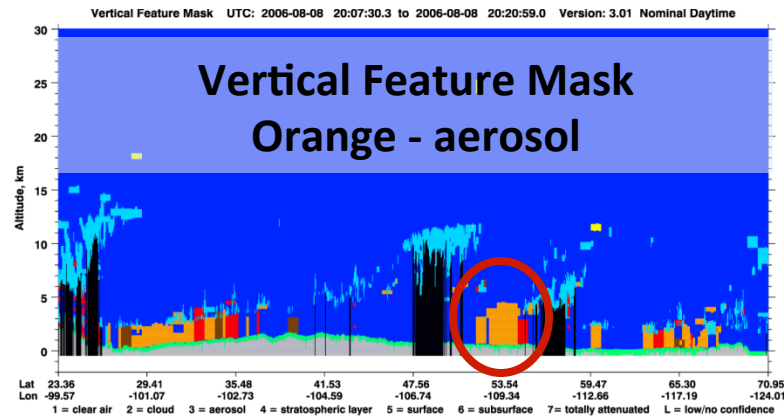
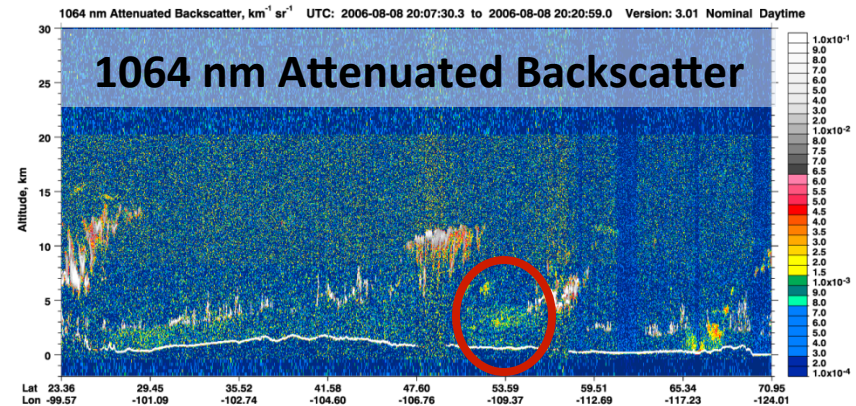
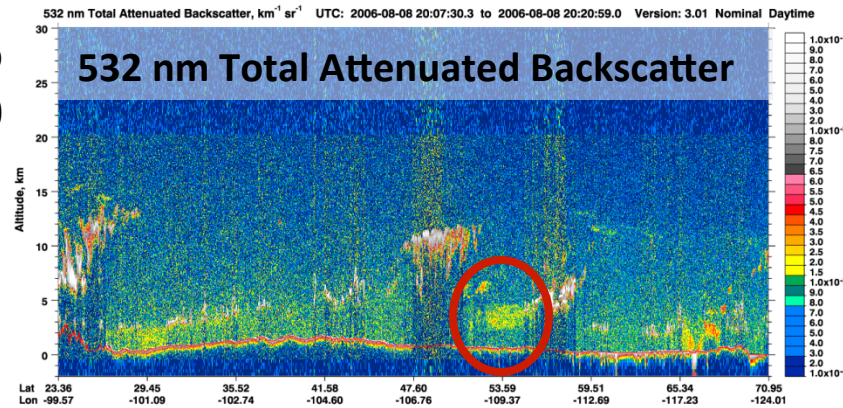
# CALIPSO overpass

## CALIPSO Curtains 08 Aug 2006 (v3)

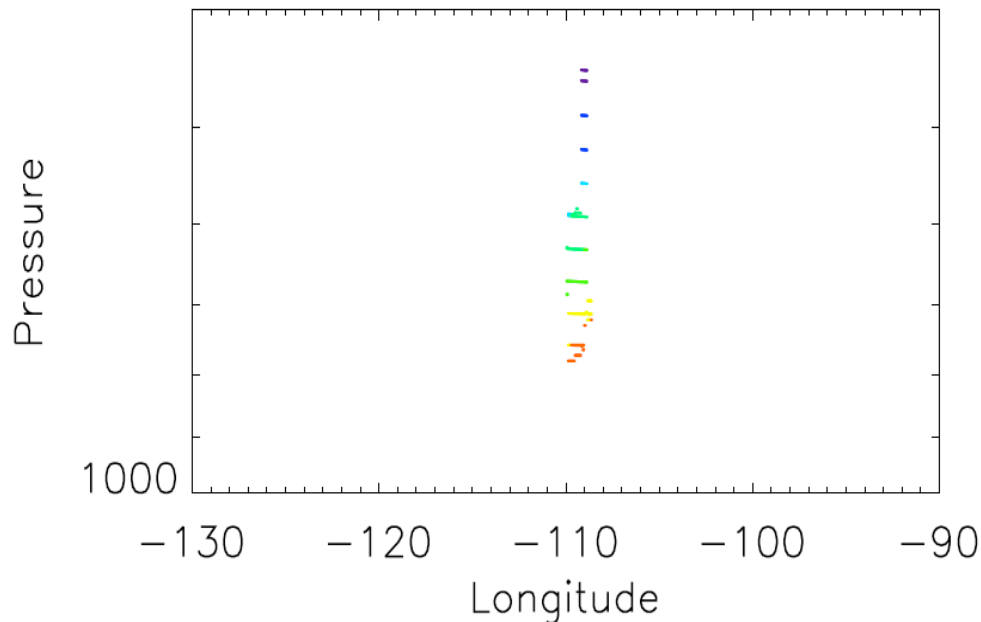
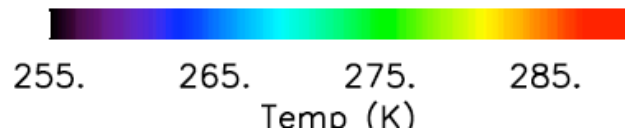
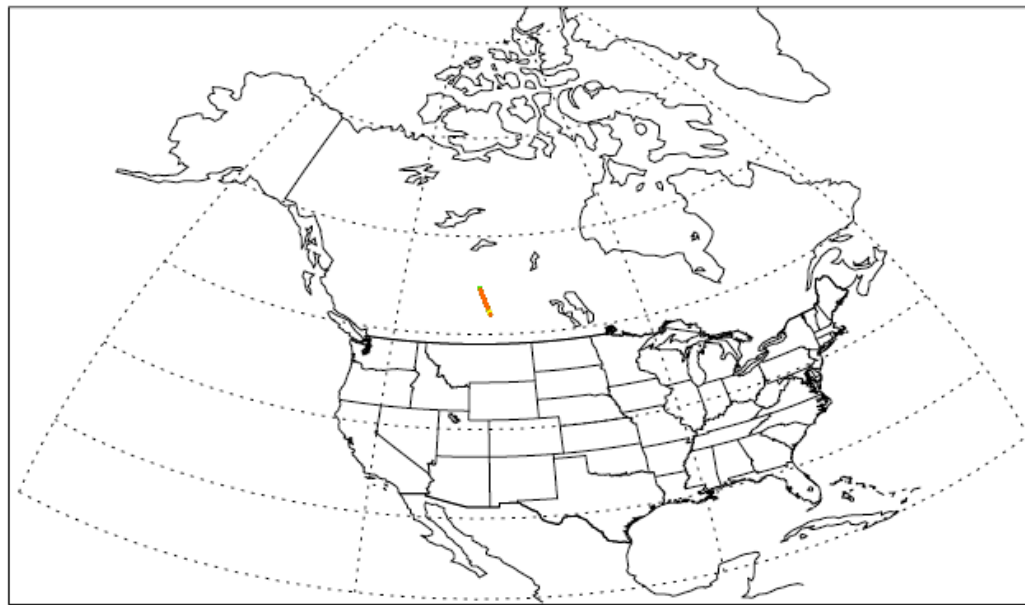
Swath  
from  
south  
to  
north



20:07  
to  
20:20





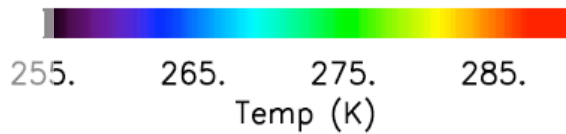


**In the Langley  
Trajectory Model  
(LaTM)**

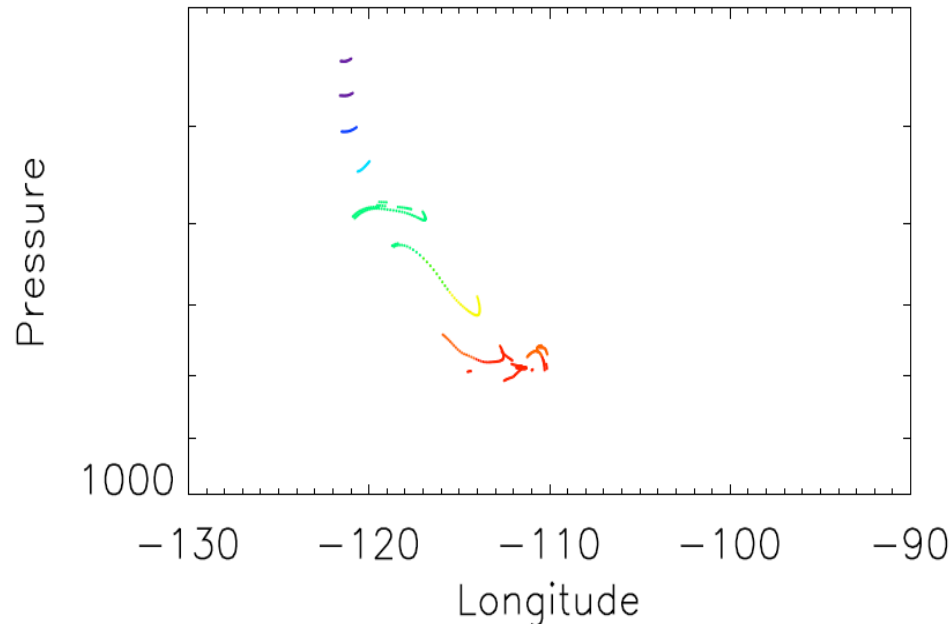
**Trajectories are  
initialized at ~1 second  
intervals along the  
CALIPSO  
smoke segment track  
and at 500m vertical  
intervals within the  
smoke plume. There is  
a 15 minute trajectory  
time step.**



**Coincidence  
with some  
fires of  
interest.**

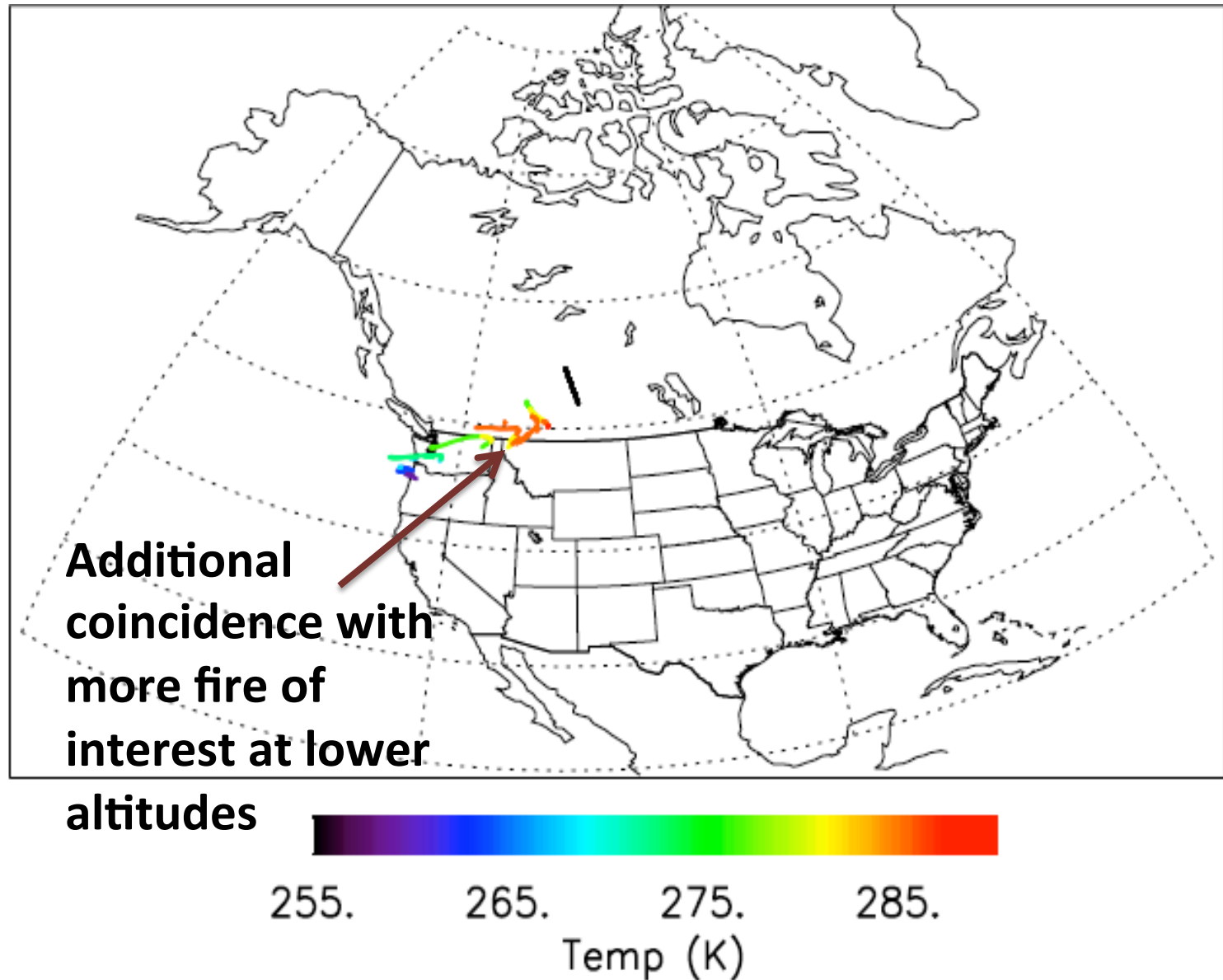


**T – 24 hrs: Back  
trajectories pass over  
“fire of interest” in  
North-Central  
Washington in the mid  
troposphere (~ 500 mb,  
~17000 ft, ~5.2 km).**



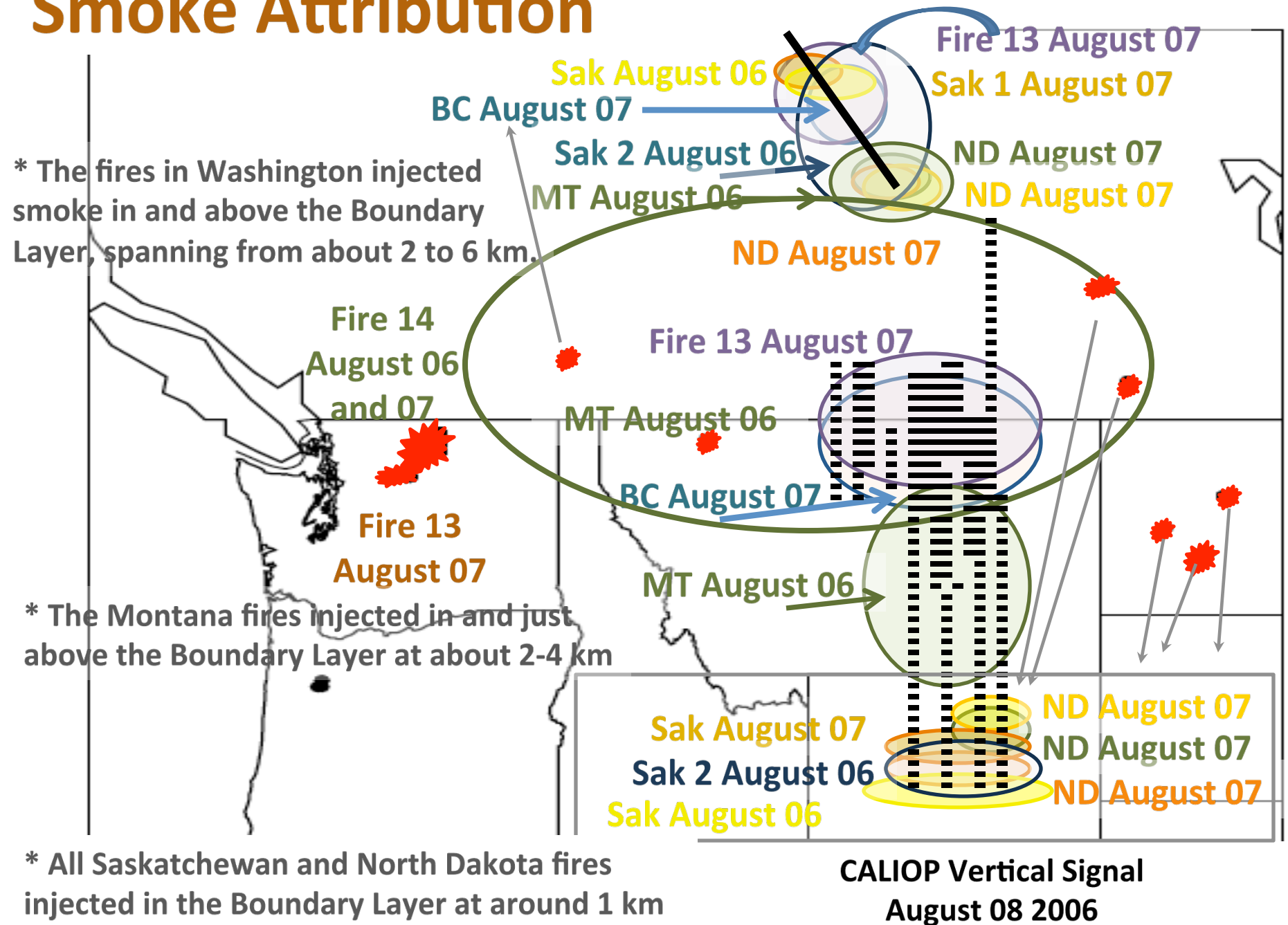


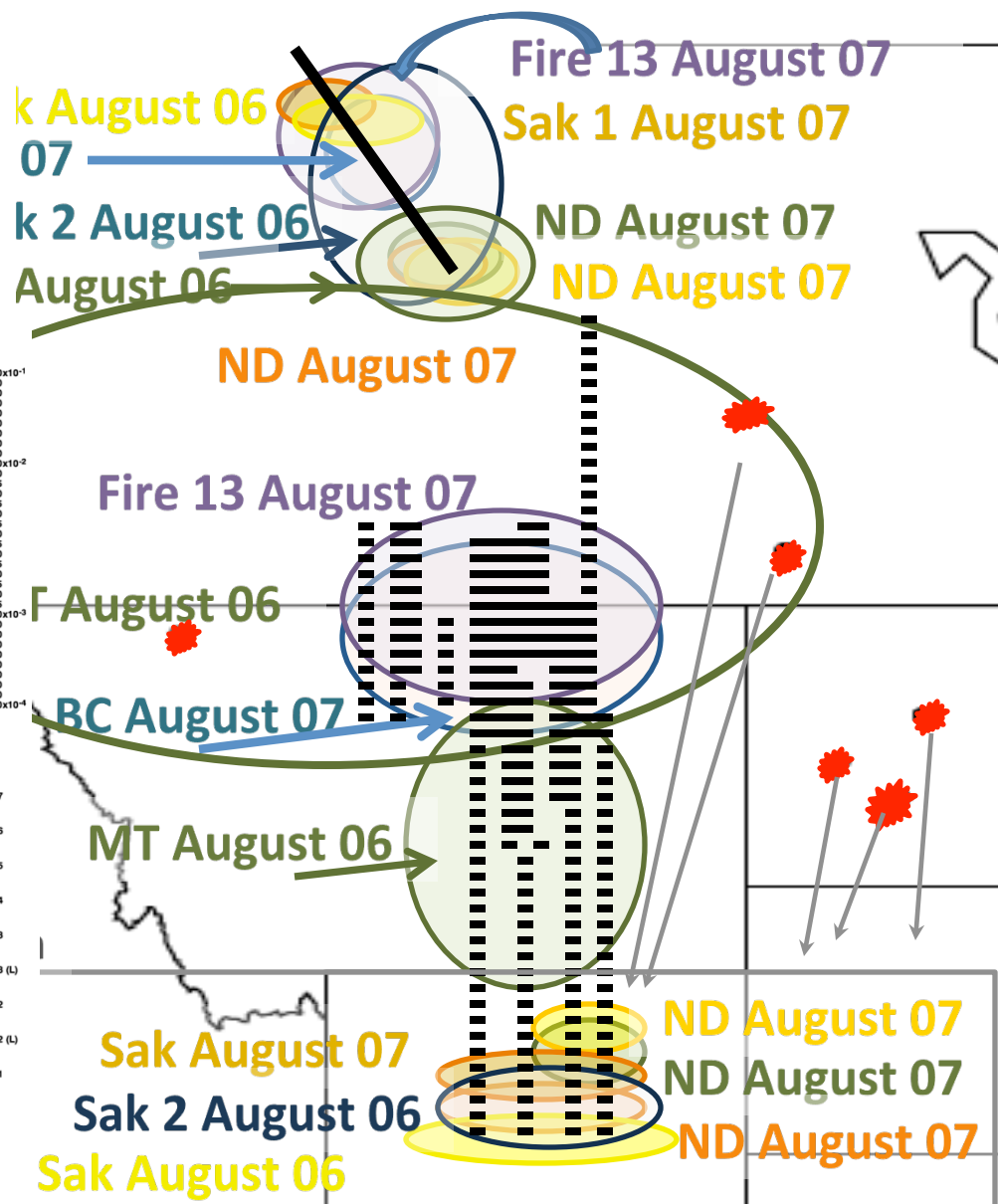
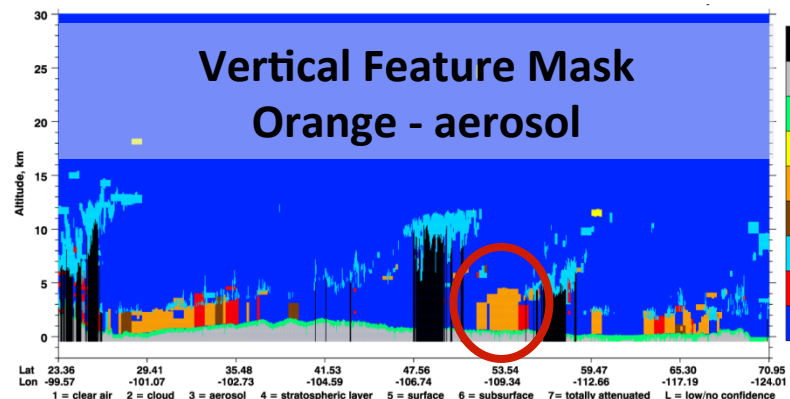
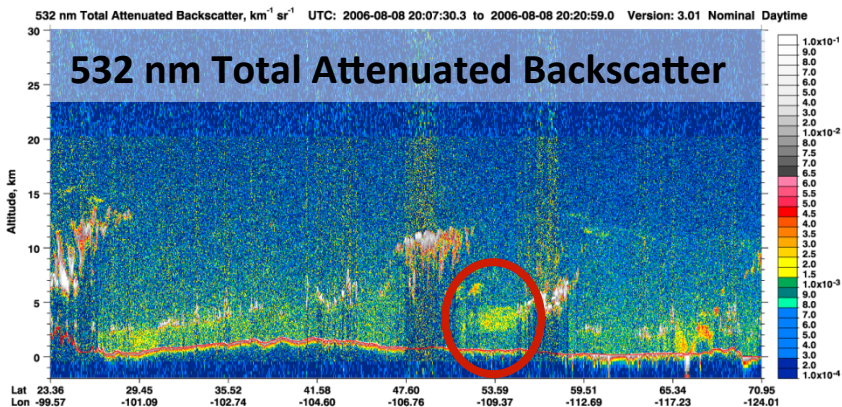
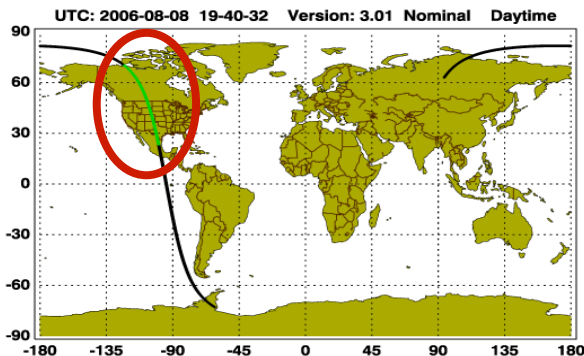
**T – 36 hrs: Back trajectories pass over “fire of interest” in North-West Montana, in the lower trop. (~ 800 mb, ~ 6500 ft, ~ 2 km)**





# Smoke Attribution






\* All Saskatchewan and North Dakota fires injected in the Boundary Layer at around 1 km

CALIOP Vertical Signal  
August 08 2006





**This plume can be attributed to 9 separate fires, burning on different days (12 fire-event-days):**

**Washington - large fire**

**August 6<sup>th</sup> (~ 3400 m);**

**August 7<sup>th</sup> (mean 3300 m, range 1900 – 6300 m);**

**Washington - medium-sized fire**

**August 7<sup>th</sup> (range 2200 – 4400 m)**

**British Columbia**

**August 7<sup>th</sup> about 3400 m**

**Montana fires – 2 of them**

**August 6<sup>th</sup> – mean 1980 m**

**Saskatchewan (2 fires)**

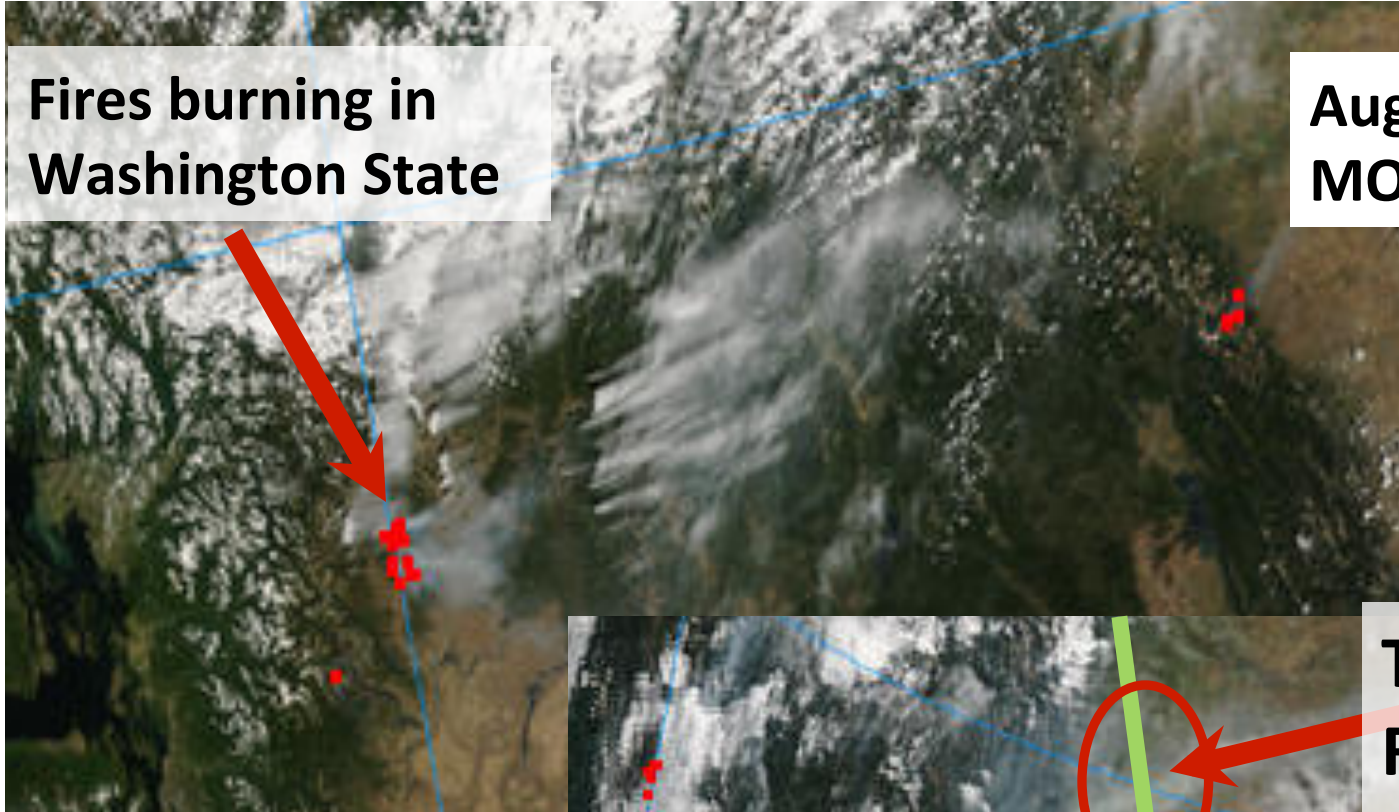
**August 6<sup>th</sup> and 7<sup>th</sup> ~ 1000 m**

**North Dakota (2 fires)      August 7<sup>th</sup> ~ 2000 m**

# A River of Smoke

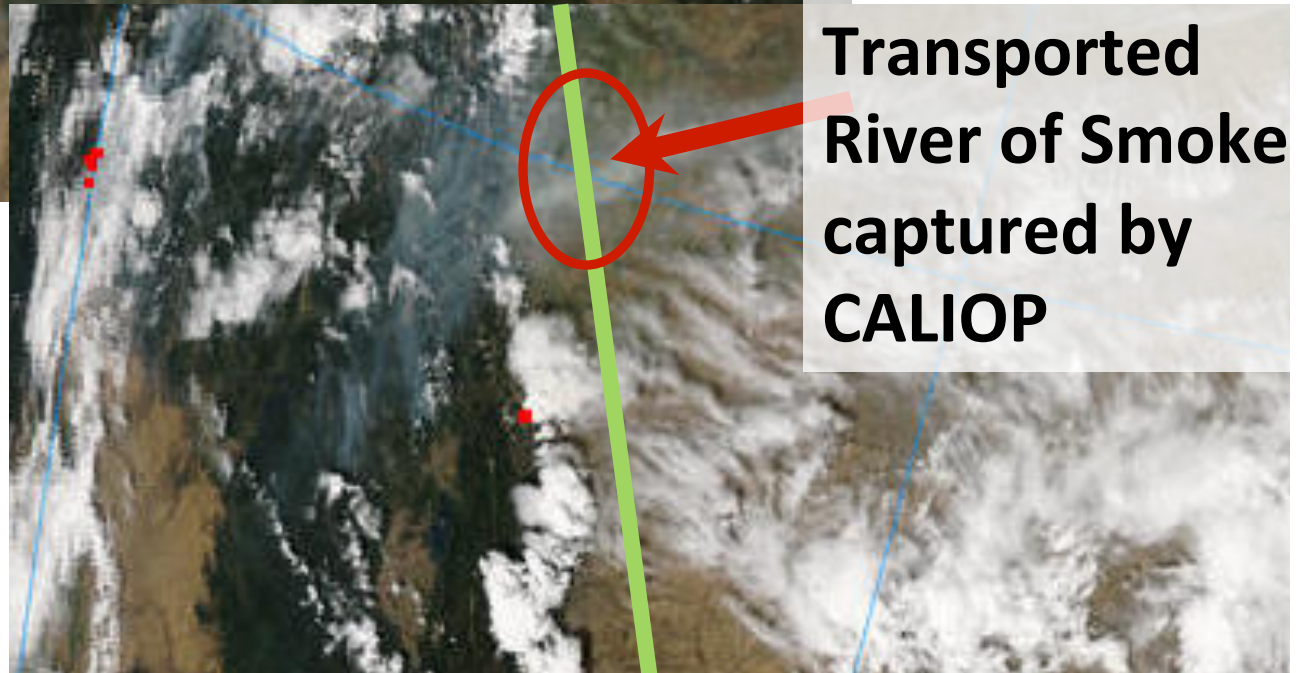
**Fires burning in  
Washington State**

**Aug 04 2006,  
MODIS Aqua**



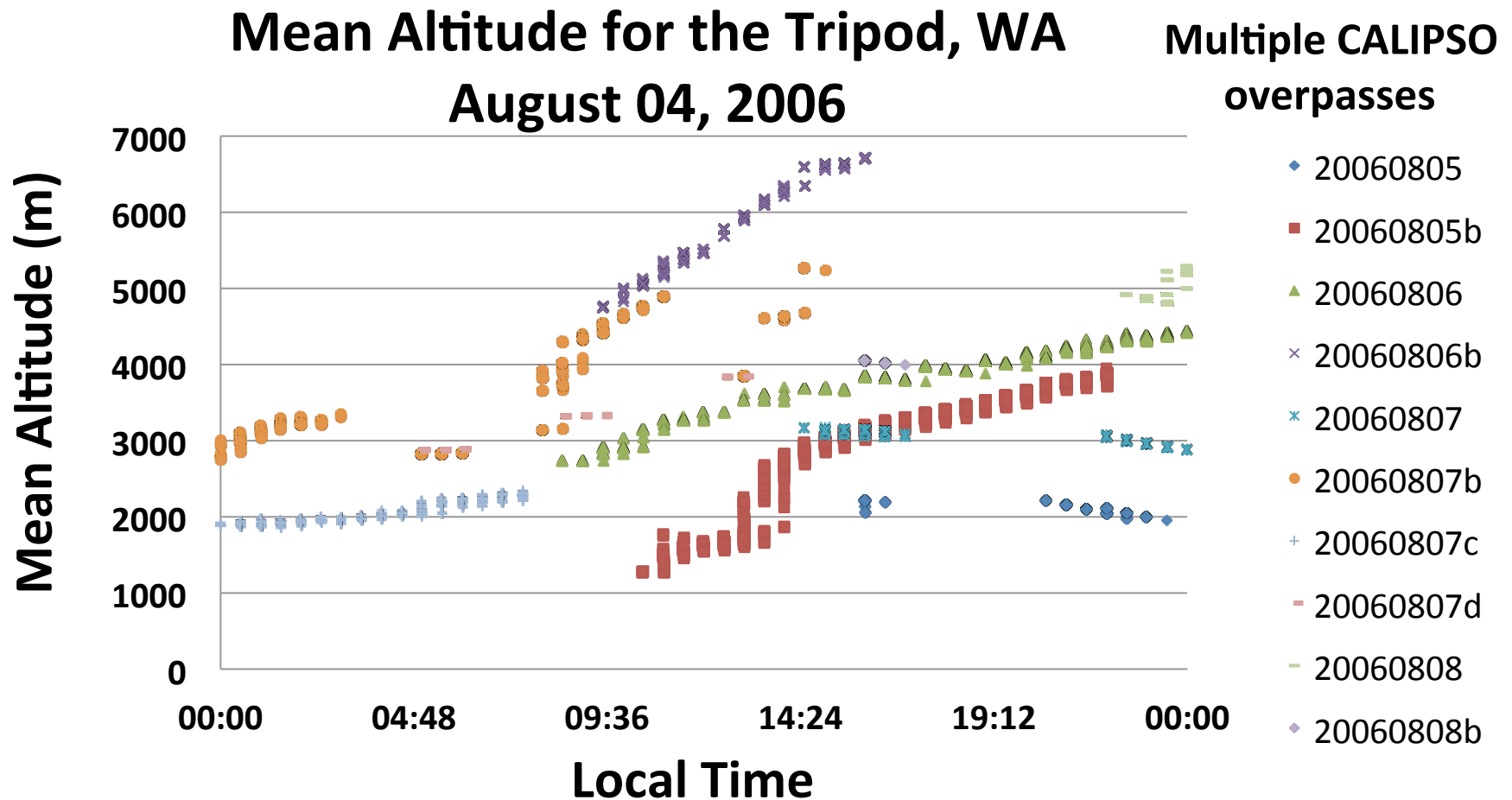
**August 08 2006  
MODIS Terra;  
CALIPSO  
overpasses**

**Transported  
River of Smoke  
captured by  
CALIOP**

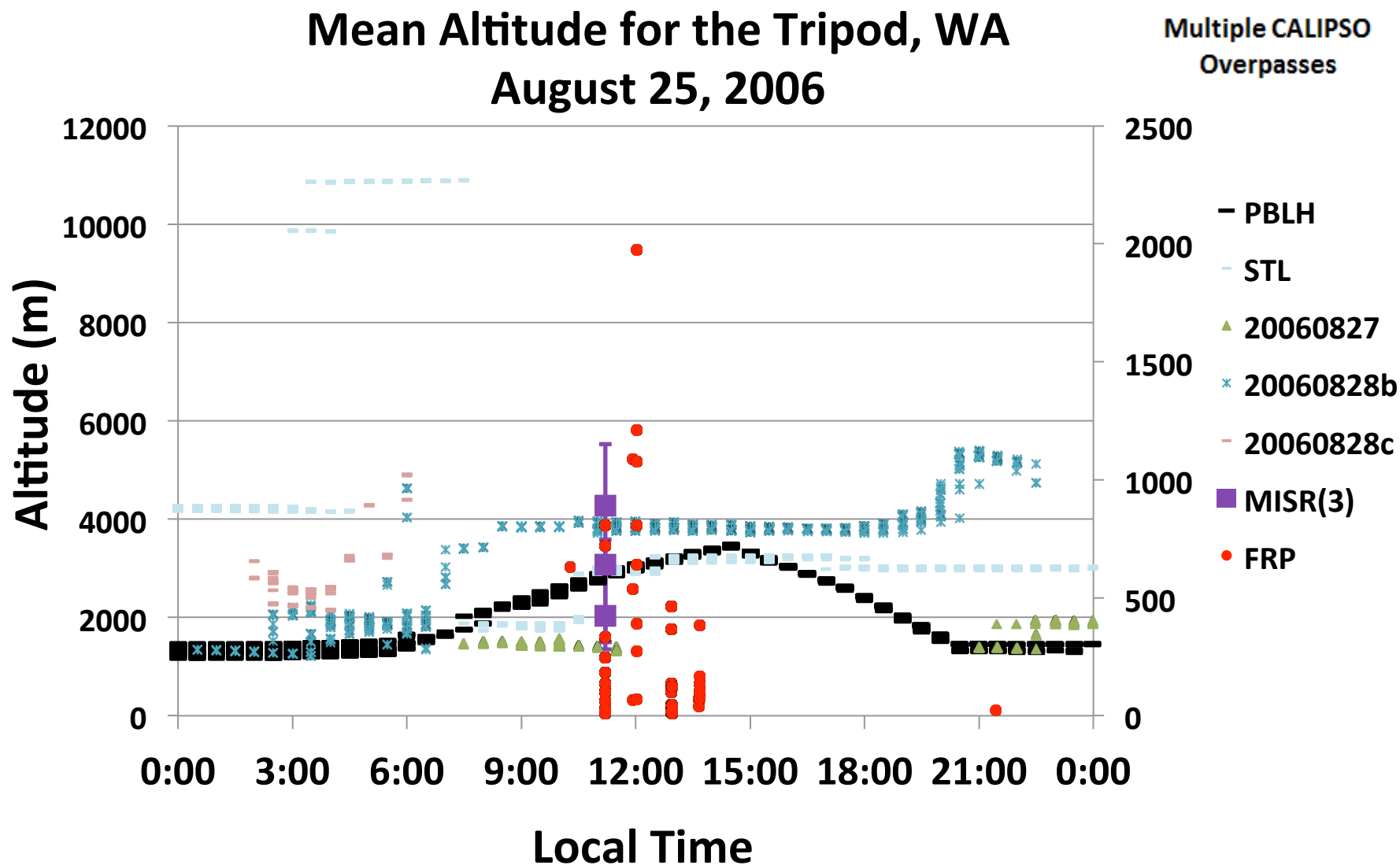




**Using multiple CALIPSO overpasses (w/ LaTM),  
the evolution of a smoke plume can be defined.  
This is unique and a new application.**



# Mean Altitude of the Tripod Fire: CALIOP and MISR data compare well



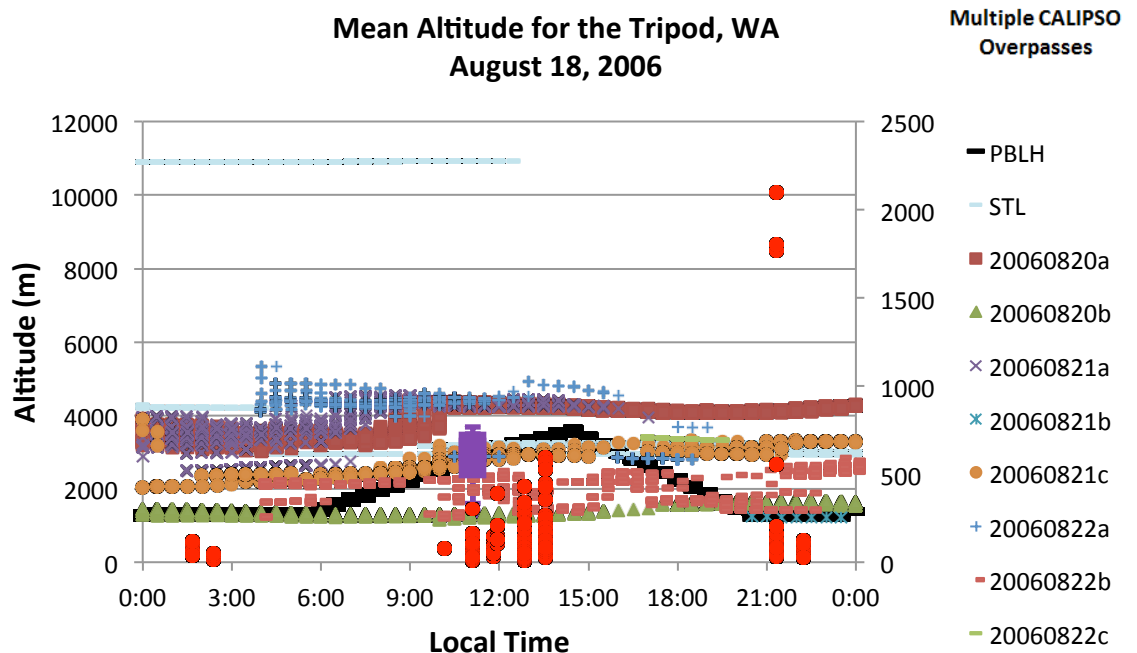
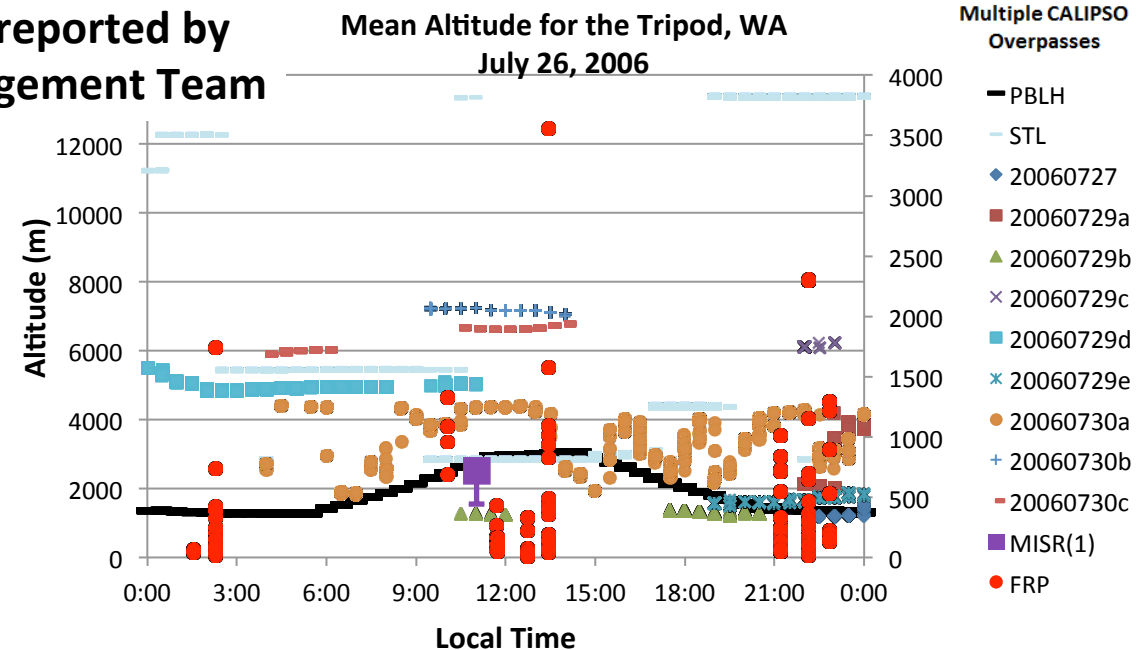


6700 – 7600 m reported by  
Incident Management Team

CALIOP data are used  
to define the daily  
smoke plume  
evolution of the  
Tripod Complex from  
July 26<sup>th</sup> through  
August 29<sup>th</sup> 2006.

MISR data capture  
morning overpasses  
for 3 days in this  
range.

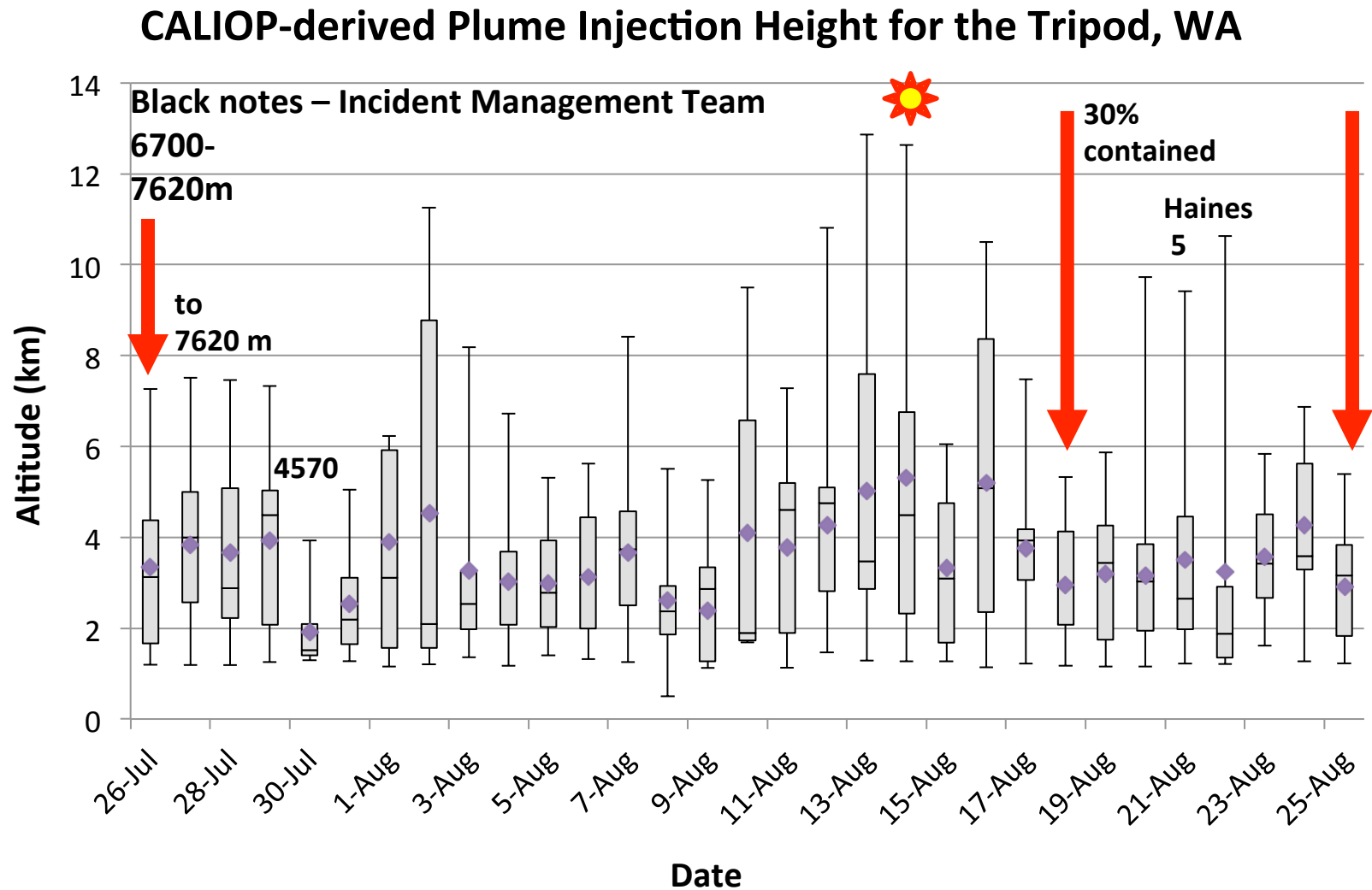
MISR low biased for  
all large plumes.



# Daily Smoke Plume Injection: Tripod Complex 2006

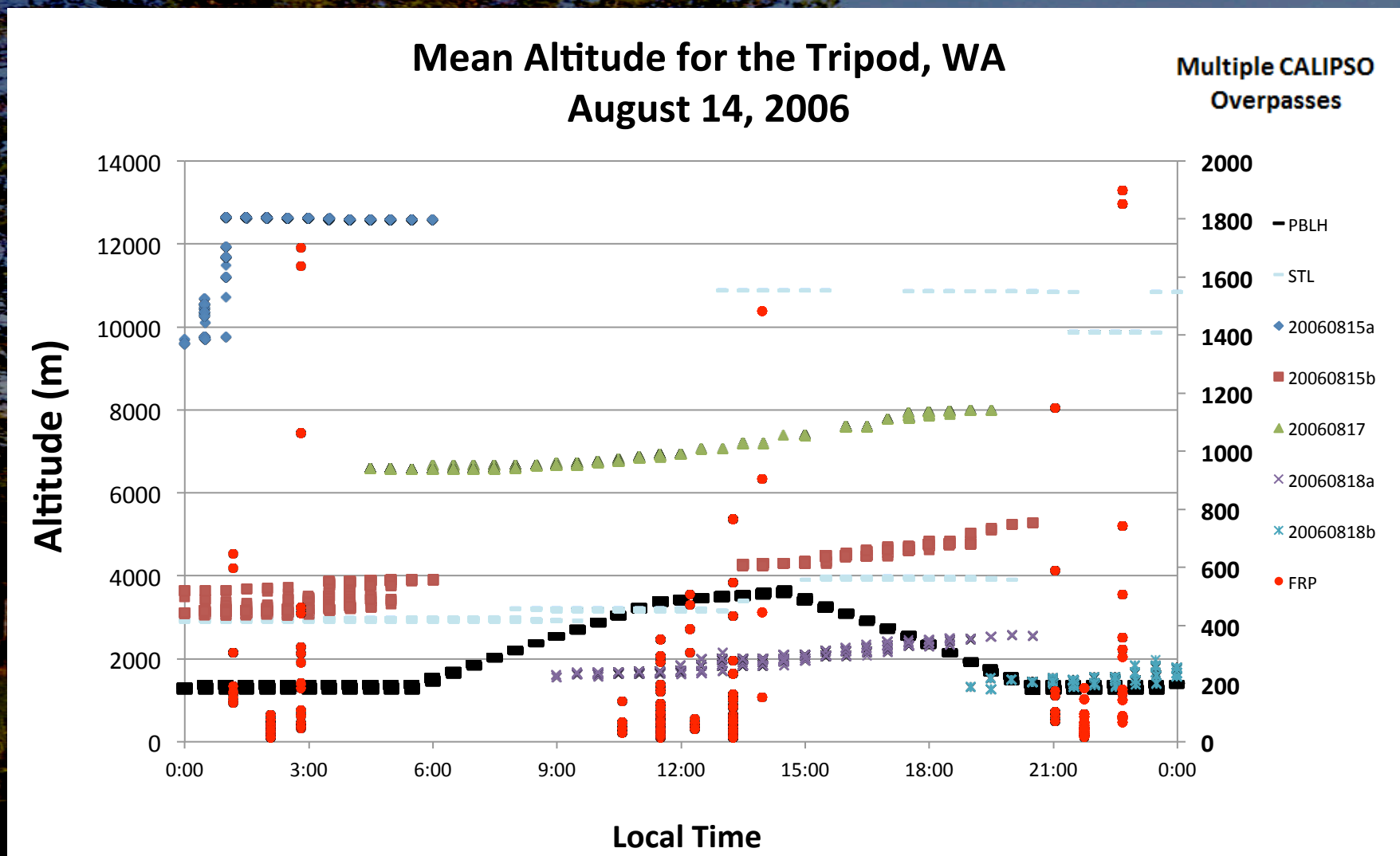
## Daily statistics (minimum, mean, median and maximum)

### Three coincident MISR days



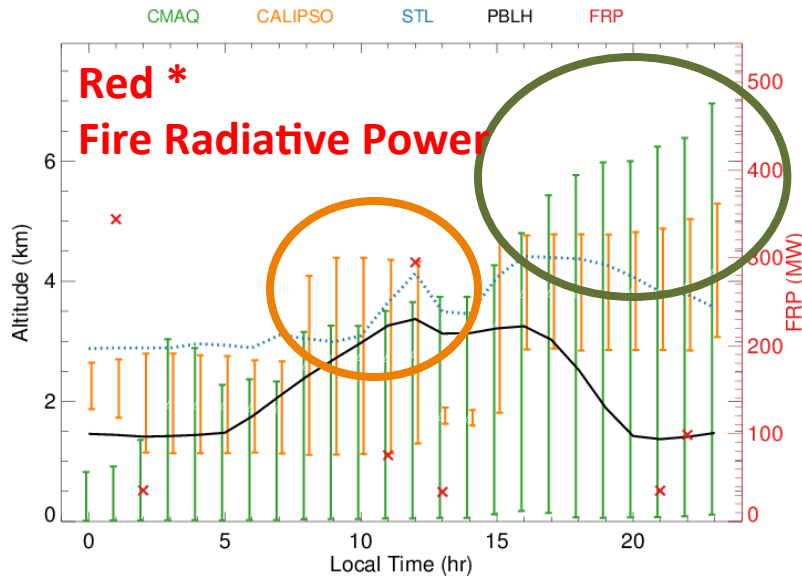


# High Fire Radiative Power and coincident smoke injection

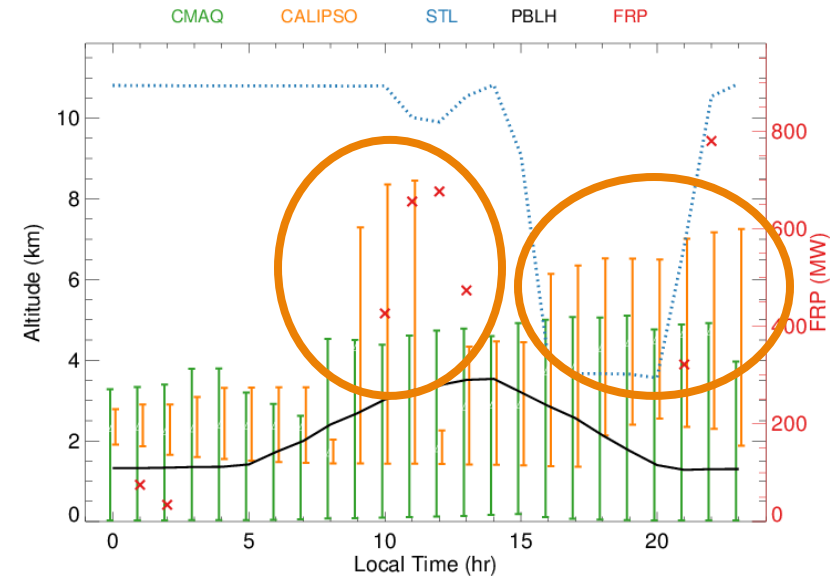


# Comparing CALIOP and CMAQ modeled Injection Height

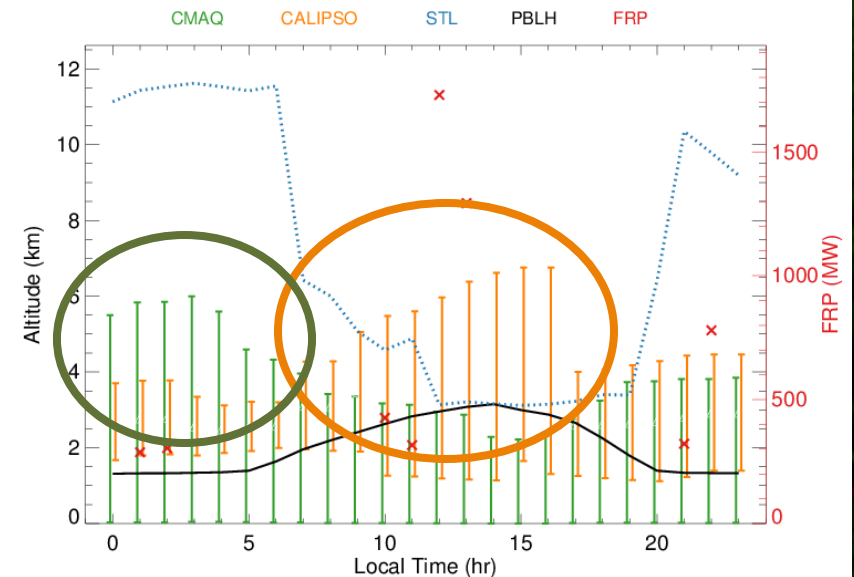
CMAQ vs. CALIPSO Plume Injection Height on 0731, 2006



CMAQ vs. CALIPSO Plume Injection Height on 0803, 2006



CMAQ vs. CALIPSO Plume Injection Height on 0804, 2006

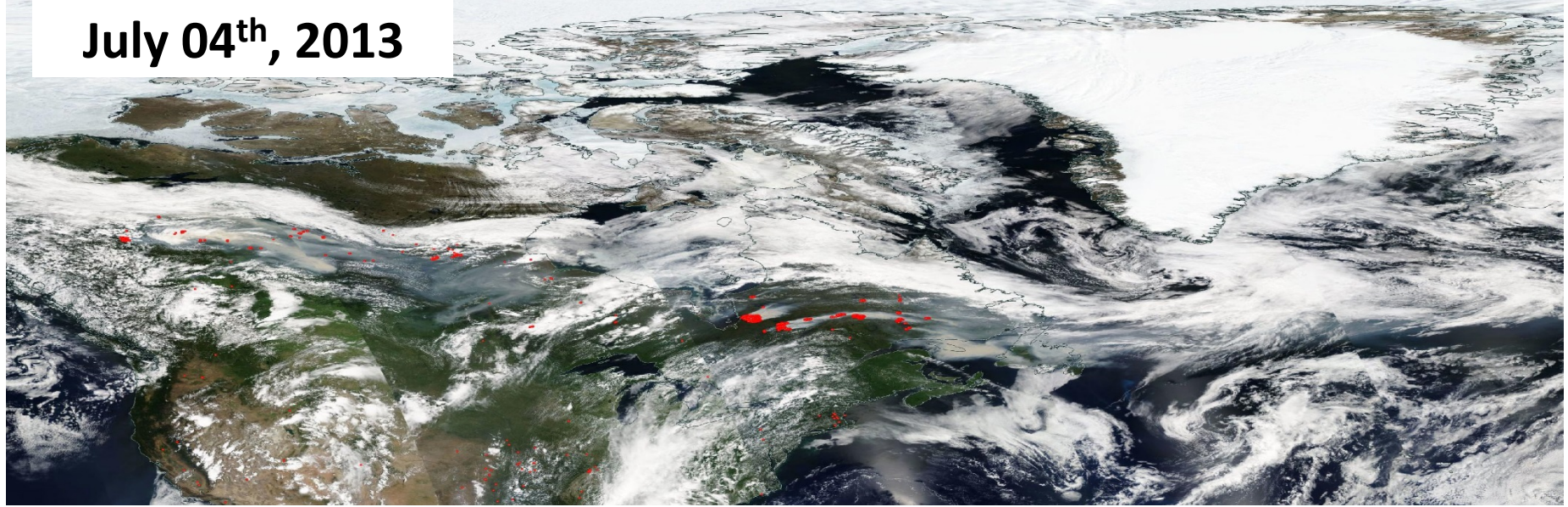


## VERY Initial Analysis

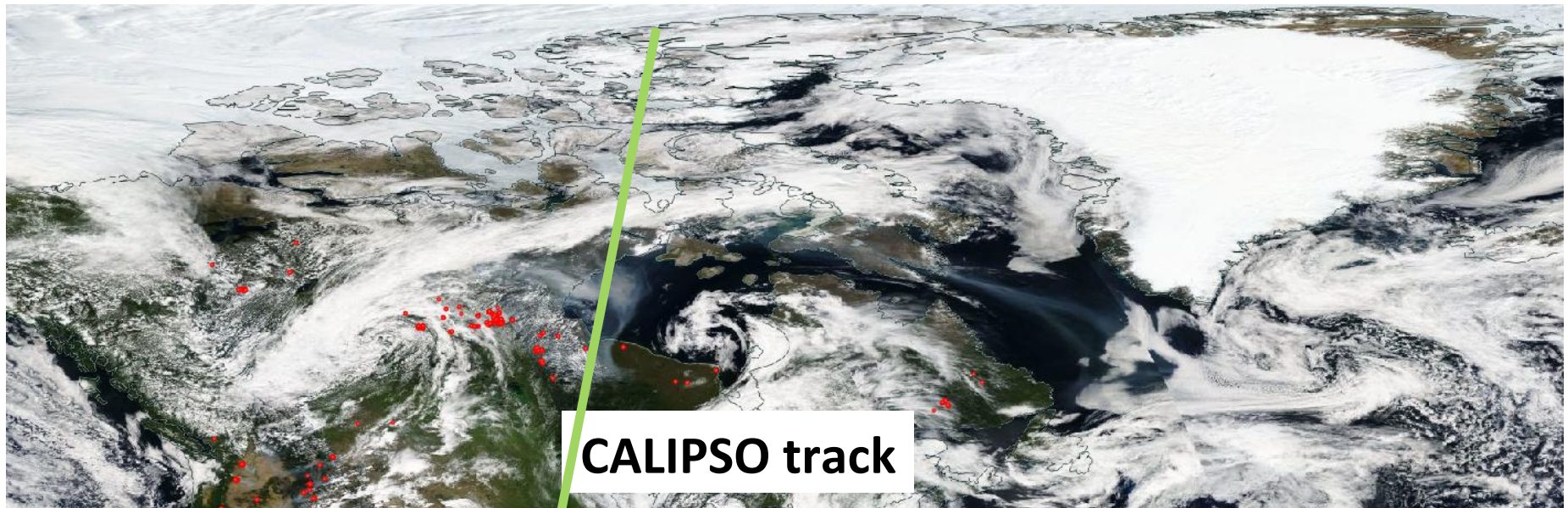
CMAQ tends to underestimate  
when the fires are burning the  
hottest (FRP) and;  
CMAQ tends to overestimate  
late and early when the FRP is  
lowest.



**July 04<sup>th</sup>, 2013**



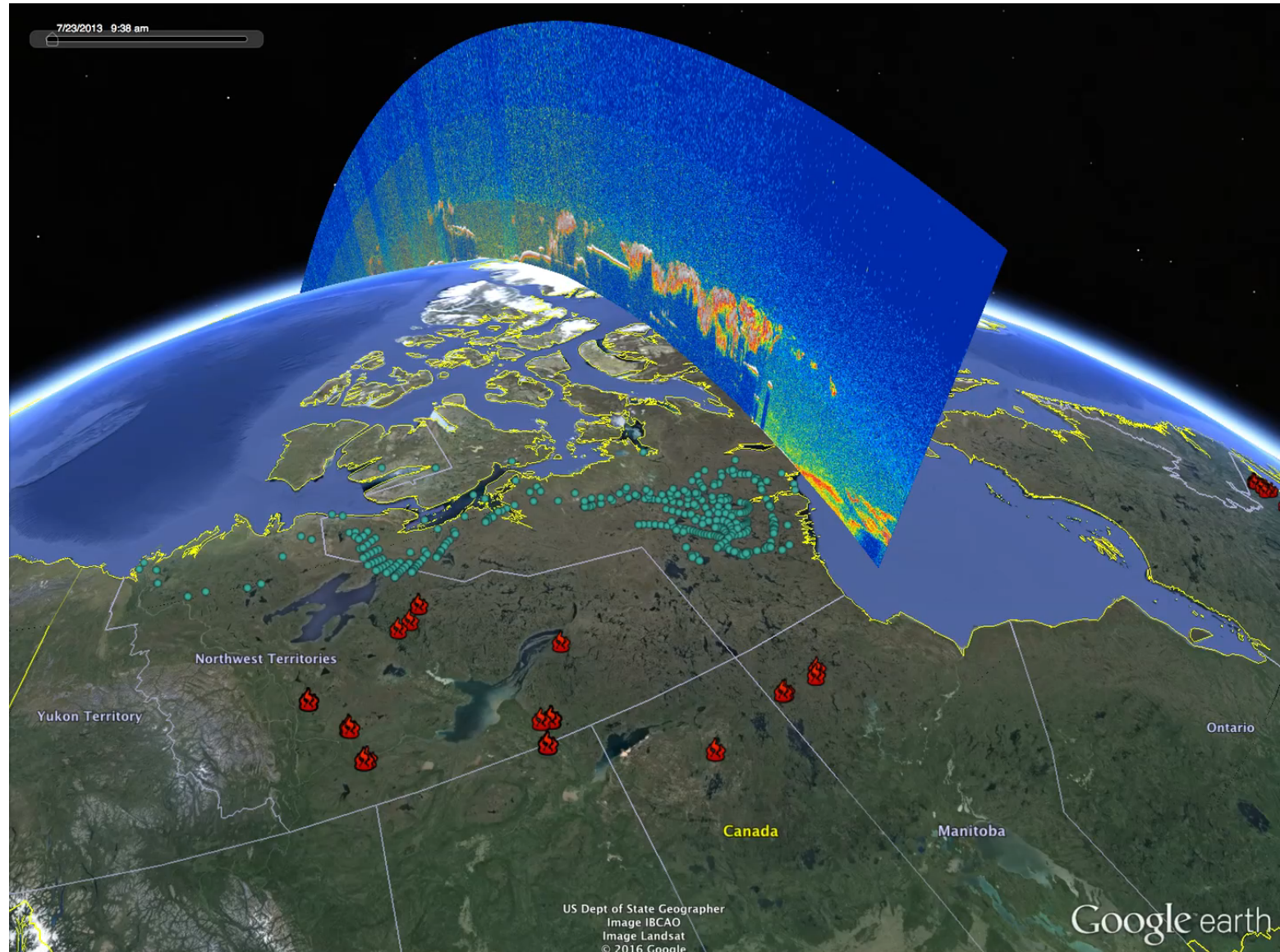
**WorldView MODIS Aqua and Terra  
July 28<sup>th</sup>, 2013**



**CALIPSO track**



**Using the LaTM, FD, samples taken from pits, and CALIOP data, we can tease apart feedbacks to climate. Specifically, preliminary analysis shows, it is not the amount of fire that burns that is directly related to deposition, rather a complicated pattern of fire and fuels, smoke injection height and transport, storms and snowfall.**





## Concluding Thoughts:

- ❖ CALIPSO data can provide a spatially and temporally random view of fire plume data, one that is not limited to particular fire types or times of day.
- ❖ One CALIOP swath can be representative of a complicated 3-D temporal and spatial story that incorporates several days, several fire events and a range of fire types from agricultural to large wildfires.
- ❖ CALIOP data can define the evolution of smoke over a day, which is a completely new process and result. **Please suggest validation data.**
- ❖ CALIOP data can be used in many application processes that define plume injection height for air quality, chemical transport models and climate change feedbacks.
- ❖ In concert, CALIOP and MISR data will add to the statistical knowledge necessary to improve our understanding of the dynamics of fire plume injection height.





# **Thank-you for listening!**

**and thanks for conversations with individuals and communities: USDA Forest Service, Environmental Protection Agency, the CALIPSO Science Team, ARCTAS/ARCPAC science teams, LARGE Team, NOAA HMS team, Brian Stocks, Louis Giglio, Charles Ichoku, Ralph Kahn, Mark Ruminski and many others.**

## **Questions?**

**And a special thanks for NASA support:**

**Lawrence Friedl and Applied Science Program Wildland Fire  
David Considine CloudSat and CALIPSO Science Team**